

Progress Report on:

Soil Gas Monitoring Activities
near the Southeastern Boundary
of the Leyden Gas Storage Facility,
Leyden, Colorado

Prepared for:

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Denver, Colorado

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Soil Gas Monitoring Activities near the Southeastern Boundary of the Leyden Gas Storage Facility, Leyden, Colorado

Executive Summary

The Leyden Gas Storage Facility is located in Jefferson County, Colorado, north of the city of Golden, and in the vicinity of the small town of Leyden.

Public Service Company of Colorado (PSC) contracted ESN Rocky Mountain to install a soil gas monitoring system near the southeast boundary of the facility. Seventeen soil gas monitoring points were installed. Soil gas samples have since been collected three separate times about two weeks apart.

The soil gas monitoring points were installed at depths up to 15' where soil conditions permitted. The monitoring points were spaced at 500' intervals, except near the residences where the spacing was as close as 50' to allow for at least one monitoring point near each structure. The total amount of boundary line monitored was about 7,000'.

Analytical methods were chosen that can detect very low concentrations of natural gas, as low as 0.01 parts per million. The method also detects the gases at a level one million times lower than USEPA and OSHA safety limits for methane.

Only very low levels of hydrocarbon gases were detected, most at or below ambient air levels. The highest total gas measurement was 5.6 parts per million. Ambient air samples contained 3 to 4 parts per million of methane. None of the gases detected pose any risk to health and safety in the areas where the monitoring points were installed.

Introduction

The Public Service Company of Colorado operates an underground gas storage facility in the abandoned Leyden Coal Mine in Jefferson County, Colorado. The mine is located north of Golden, Colorado, near the small town of (Leyden see map in Appendix A). The facility began operations about 1960. The facility stores about 3 bcf of gas and has a maximum working capacity of about 2.2 bcf. The facility provides the Denver area with up to 20% of its winter peaking demands and enables PSC to purchase gas at off-peak prices (USEPA, 1998, EPA-430-R-98-019).

In the northwest corner of Section 35, a monitoring (observation) well was recently drilled (Well No. 36) that encountered storage gas at 775'. This well is located approximately 175' south from the mapped boundary of the mine workings, and approximately 200' north of the buffer zone boundary of the Leyden Gas Storage Facility. This is based on surface maps provided by Public Service Company of Colorado (PSC) which show well locations and historical data of the mine workings. The discovery of the gas in Well No. 36 prompted concern about potential leakage to the surface in areas where homes exist near Leyden.

ESN installed soil gas monitoring wells at depths up to 15' along the boundary of the buffer zone. The monitoring methods used for this project included installing permanent monitoring well points and withdrawing the soil gases at a later date so that soil gases can be measured in equilibrium conditions. This method of soil gas sampling allows the gases that were generated artificially during drilling to disperse and the soil gases to return to equilibrium after a period of time.

The procedures used to analyze soil gas samples are based on gas chromatography methods used to detect trace levels of naturally occurring hydrocarbons in oil and gas exploration program. These methods are far more sensitive than those typically used to simply measure gas content for health and safety purposes.

Selection of Monitoring Locations

Approximately 7,000 feet of the southwestern part of the Leyden boundary was selected for monitoring (see location map in Appendix A). Monitoring points along this boundary were placed at 500' spacing for areas *not* near homes or other structures. Where homes are present, the spacing was tightened to equal the lot spacing so that at least one monitoring point was installed near each lot or structure. This put monitoring points as close as 50' behind some of the home lots in Leyden.

A total of 19 monitoring points were proposed for the study. One was not installed due to topography limitations and another due to close proximity to underground utilities. The remaining 17 points adequately cover the boundary with no significant gaps in data, and there is at least one point near the property line of each existing house along the boundary.

ESN has also collected soil gas samples from other locations in the region not associated with the gas storage facility for the purpose of making comparisons. One sample was collected during this study from a well point behind ESN's office in Golden. Others have been collected and analyzed from various locations north and south of the Golden area.

Monitoring Point Installation

The surface soil in this area consist of Pleistocene age alluviums and colluviums, which contain an abundance of glacial cobbles and gravel mixed with sand, silt and clay. Auger Drilling or Direct Push Probing is very difficult in this type of soil and generates significant amounts of friction and heat at the probe tip or drill bit. Sampling such a test hole immediately after probing will measure many gases that have been liberated from the soil by *thermal desorption* or *bit metamorphosis*. This effect has been reported in the literature (Witicar, M.J.,1990) and demonstrated in previous studies (Fontana, 1999) around Leyden and in other studies familiar to ESN Rocky Mountain.

Because of the above mentioned effect of probing, sampling at the installed monitoring points was conducted a few days after the initial installation, and then at two week intervals to see if there was a stabilizing effect. It appeared that there was a small amount of disturbed gas effect in the first round of sampling that decreased to background values in the later two rounds of sampling. Figure 1 is a schematic of the monitoring point installation. The monitoring points were constructed as follows:

1. A heavy-duty Direct Push rig (StrataProbe) was used to push a hole up to 15' deep using 1.5" steel probe rod with a solid drive point tip. The rod was then removed from the hole. (Where shallow ground water was encountered, or bedrock refusal, the test holes were set at a shallower depth.)
2. Approximately 6" of monitoring well grade 10-20 mesh silica sand was poured into the bottom of the hole.
3. A 24" long, 1/2" ID, PVC well screen with 0.01" mill slots was attached to a length of 1/4" polyethylene tubing and lowered through the probe rod to the bottom of the test hole, resting on top of the 6 inches of sand. (See photograph of screen in Figure 2)
4. The 10-20-mesh sand was poured around the well screen to 6" above the screen.

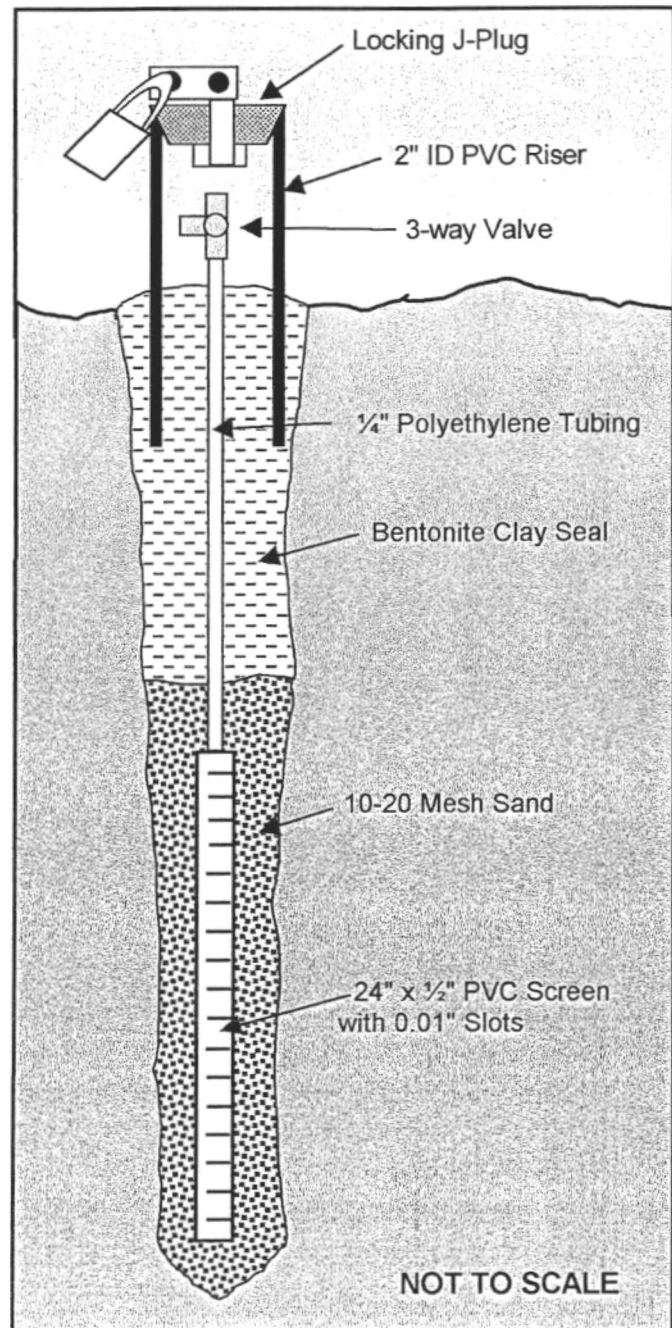


Figure 1. Soil Gas Monitoring Well Point Construction

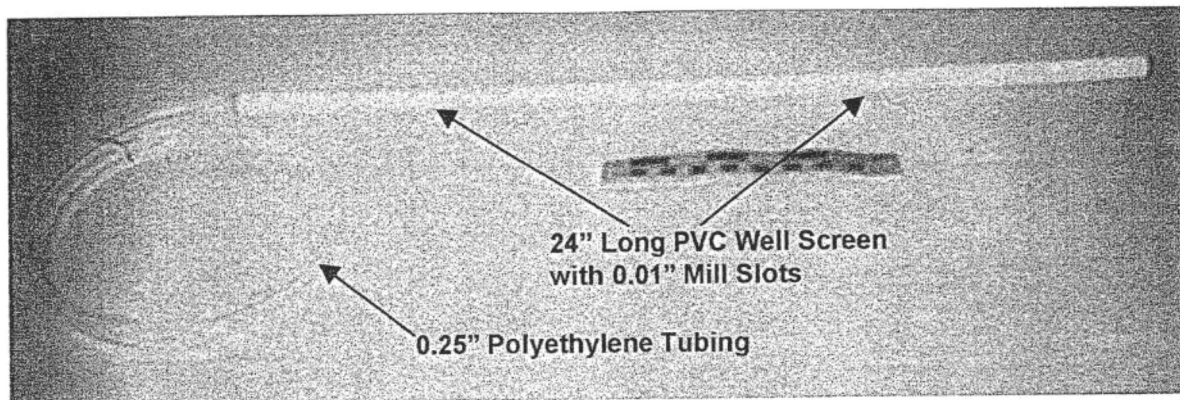


Figure 2. Photograph of Soil Gas Well Screen and Tubing used to construct monitoring points.

5. Granular bentonite chips (10 mesh) were poured on top of the sand pack and were hydrated with water in 24" lifts or less, creating the seal above the screened interval. This forms the clay seal preventing entry of atmospheric air into the screened interval.
6. A 24" long by 2" ID PVC riser was inserted in the upper part of the hole, over the tubing, and was packed and sealed with hydrated bentonite chips. The top of the riser was left sticking up about 1-3 inches above the soil surface.
7. A plastic 3-way valve was attached to the top end of the $\frac{1}{4}$ " tubing and was tucked into the top of the 2" riser. The valve was left closed.
8. For protection from tampering, a "J-Plug" was inserted in the top of the 2" riser and locked with a padlock. ESN has the only keys to the padlocks.

Monitoring points 1 through 17 were installed on Friday, January 28, 2000, and points 18 and 19 were installed on Monday, January 31. The first sampling event was on February 3.

Three of the test holes (numbers 2, 6 and 16) were continuously cored to obtain lithologic soil data for the area and to observe if ground water was shallow in any of the areas.

Only five monitoring points were installed to 15'. The remaining points had to be installed shallower due to either bedrock refusal, or shallow ground water saturation. The screened depth interval for each point is listed in the Soil Gas Data Tables in Appendix B.

Monitoring Point Sampling Procedures

Figure 3 shows an installed monitoring point connected to a sample pump and gas sample bag. The monitoring points are sampled according to the following procedure:

1. The peristaltic pump is fitted with a clean length of $\frac{3}{8}$ " silicone tubing. One end is attached to the 3-way valve on the monitoring point, and the other is attached to the valve on the Tedlar bag.



Figure 3. . Collecting a soil gas sample at an installed monitoring point.

2. Valve on the monitoring point and the Tedlar bag are opened.
3. The peristaltic sample pump is then turned on to fill the Tedlar bag. (The total volume of the screen and the tubing is between 100cc and 140cc, depending on the length of the tubing. The system should be purged with at least 4 system volumes to remove all of the stagnant gas in the tubing and screen). The Tedlar bag is allowed to fill completely full, which is approximately 1,000cc. This will purge the system between 7 and 10 times the volume, more than enough to purge the system.
4. The pump is then shut off. The Tedlar bag is disconnected from the pump and the contents of the bag is expelled.
5. The bag is then reconnected to the pump and filled with another volume of soil gas.
6. The valves are closed on both the Tedlar bag and the monitoring point.
7. The bag is labeled and placed into a closed container, out of direct sunlight. The samples are delivered to the Lab the same day for analysis.

The first set of soil gas samples was collected on February 3rd and 4th, which is 3-5 days after the installations. The second round of sampling was done on February 17, and the third round to date was done on March 7.

Soil Gas Analysis

Gas samples were analyzed by gas chromatography as summarized below. Additional details of this analytical method are found in TEG's Standard Operating Procedure NGC111.

Gas samples were analyzed for light hydrocarbon content on a Hewlett-Packard model 5890 Gas Chromatograph (GC) equipped with a Flame Ionization Detector (FID). The sample is introduced through a sample loop and is injected by an automatic 10-port gas-sampling valve. The gas component separation is done on a 1/8" stainless steel column packed with activated alumina. Compounds measured and detected include methane, ethane, ethene (ethylene), propane, propene (propylene), iso-butane, normal-butane, iso-pentane, normal-pentane, iso-hexane and normal-hexane. A pre-cut column is used to separate any hydrocarbons heavier than hexene and purge them from the system. The instrument is tuned and calibrated to measure these hydrocarbons at very low concentrations, as low as 10 parts per billion (0.01ppm) by volume.

Results are reported to the nearest 0.01 parts per million. It should be noted that 1 part per million is one ten-thousandth of a percent, 0.0000001%, of gas by volume in air. The gases are totaled and also reported as total gas in ppm. The composition of the gas (through butane) is also calculated by dividing amount of each component by the total gas (alkanes only) and multiplying by 100%. Therefore, each component is reported as a percentage of the total gas detected. These gas ratios can be used to compare different gas sources to each other.

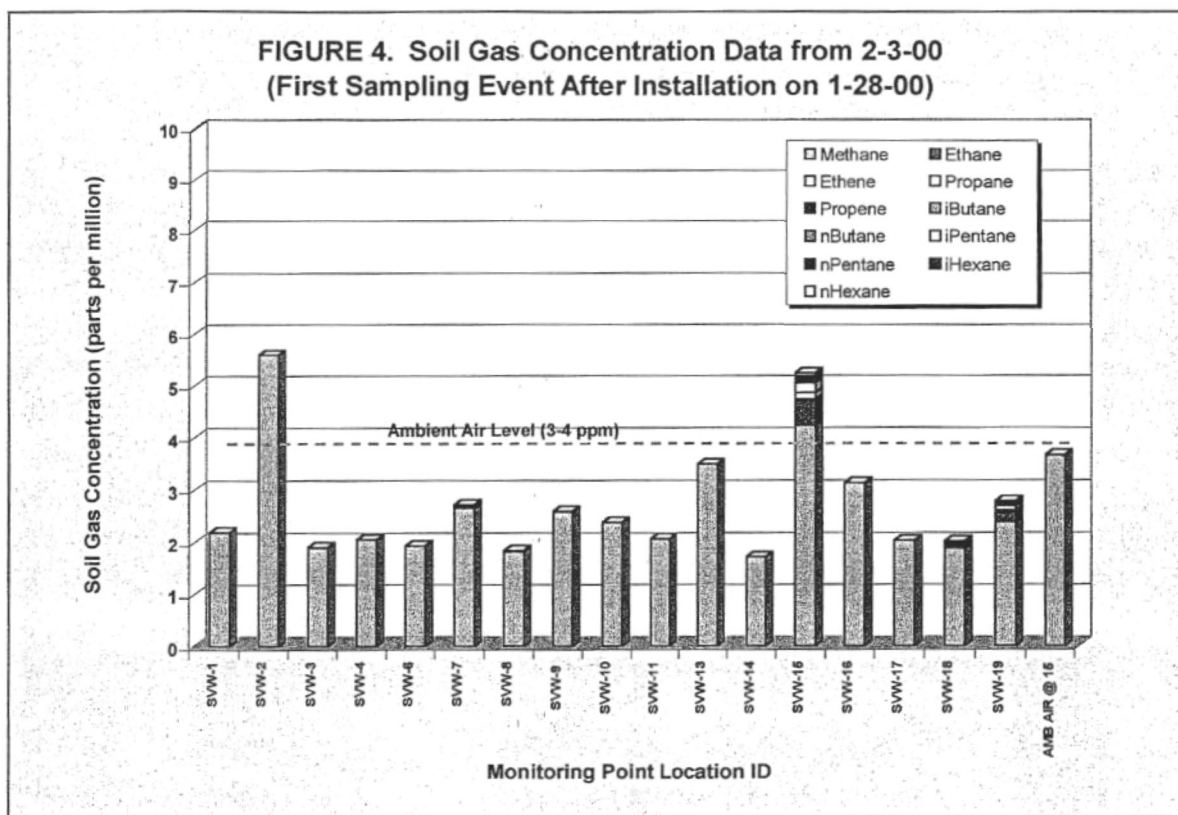
Quality Control: The Gas Chromatographs are calibrated at the beginning of the day and a closing calibration is run at the end of the day or analysis run. Daily instrument blanks, method blanks, and laboratory duplicates are run to confirm proper operation of the instrument and method. Field duplicates were also analyzed to demonstrate reproducible field sampling techniques. Traceable and certified standards are used to calibrate the instruments.

Soil Gas Results

The complete results of the soil gas analysis can be found in Appendix B gas data. The results are summarized below, and in Figures 4-7.

February 3 Sampling Event: The first set of samples (Figure 4) measured total hydrocarbons near atmospheric levels of methane. An ambient air sample was collected on that day and contained between 3 and 4 ppm methane, which is typical for air in this area. The total hydrocarbons detected in all of the samples ranged from 1.7ppm to 5.2ppm, also typical for soils. Low levels of the alkanes (ethane, propane, butane, etc.) were also detected, all less than one ppm, which are considered typical to low levels for this area.

Locations 7, 15, 18, and 19 detected levels of ethane, propane and butane less than 1ppm. At these very low levels, it is not valid to compare the composition of these samples to that of the gas storage reservoir, since ambient air methane is still a significant percentage of the mix (at least half). A table of compositions from previous studies is in appendix B. The table shows that samples collected from other areas show results similar to these and are not unusual.



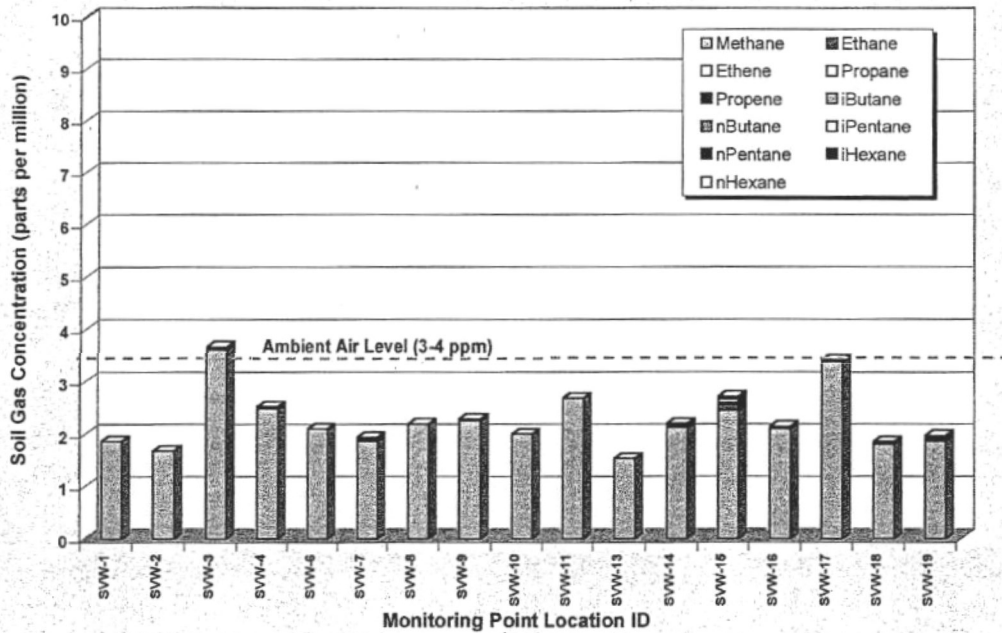
Location SVW-9 had some pentane and hexane in the sample. This was suspected to be from fuel contamination (vehicle exhaust, etc.), so the sample was recollected the next day to show that these gases were not present in the test hole.

February 17 Sampling Event: Again, the gas concentrations were at or below ambient levels of methane. The few samples that had slightly higher values in the previous event were now below ambient levels. Only location 15 still showed ethane through butane hydrocarbons, at lower values than the first event. This indicates that some of the gases measured in the first event were residual effects of sampling only a few days after the monitoring point installation.

March 7 Sampling Event: The third sampling event was similar to the second event, indicating that the monitoring points were stable by the second event. Very few detectable ethane and heavier alkanes were present in this round of sampling. The alkanes were barely detected at location 15.

Quality Control Samples: All field duplicates and laboratory duplicates repeated favorably. The samples that were collected on March 7 were not analyzed until March 15 due to an instrument problem in the lab. This would have the effect of possible slightly lower values.

**FIGURE 5. Soil Gas Concentration Data from 2-17-00
(Second Sampling Event After Installation on 1-28-00)**



**FIGURE 6. Soil Gas Concentration Data from 3-7-00
(Third Sampling Event After Installation on 1-28-00)**

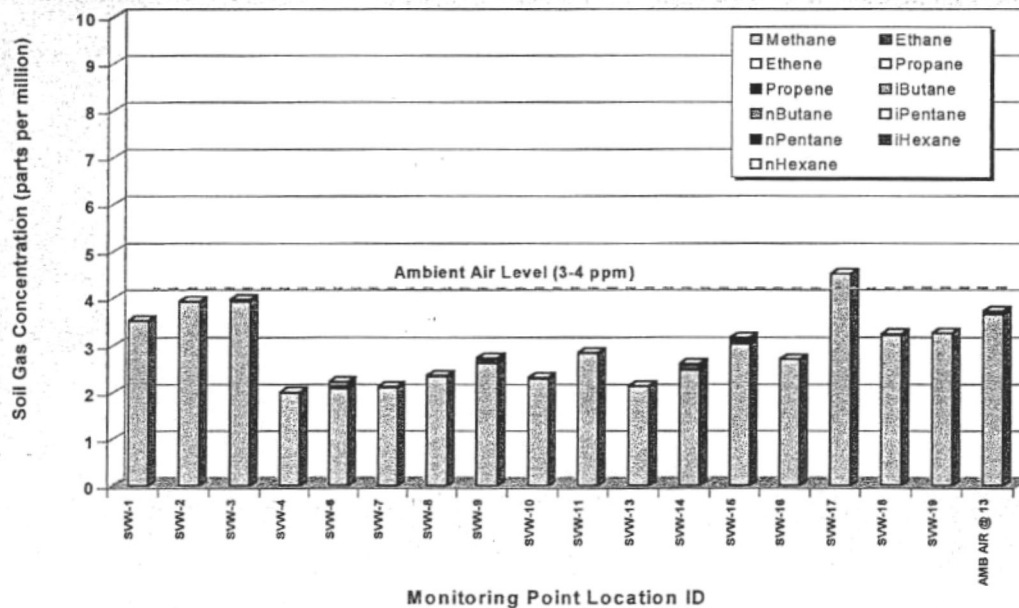
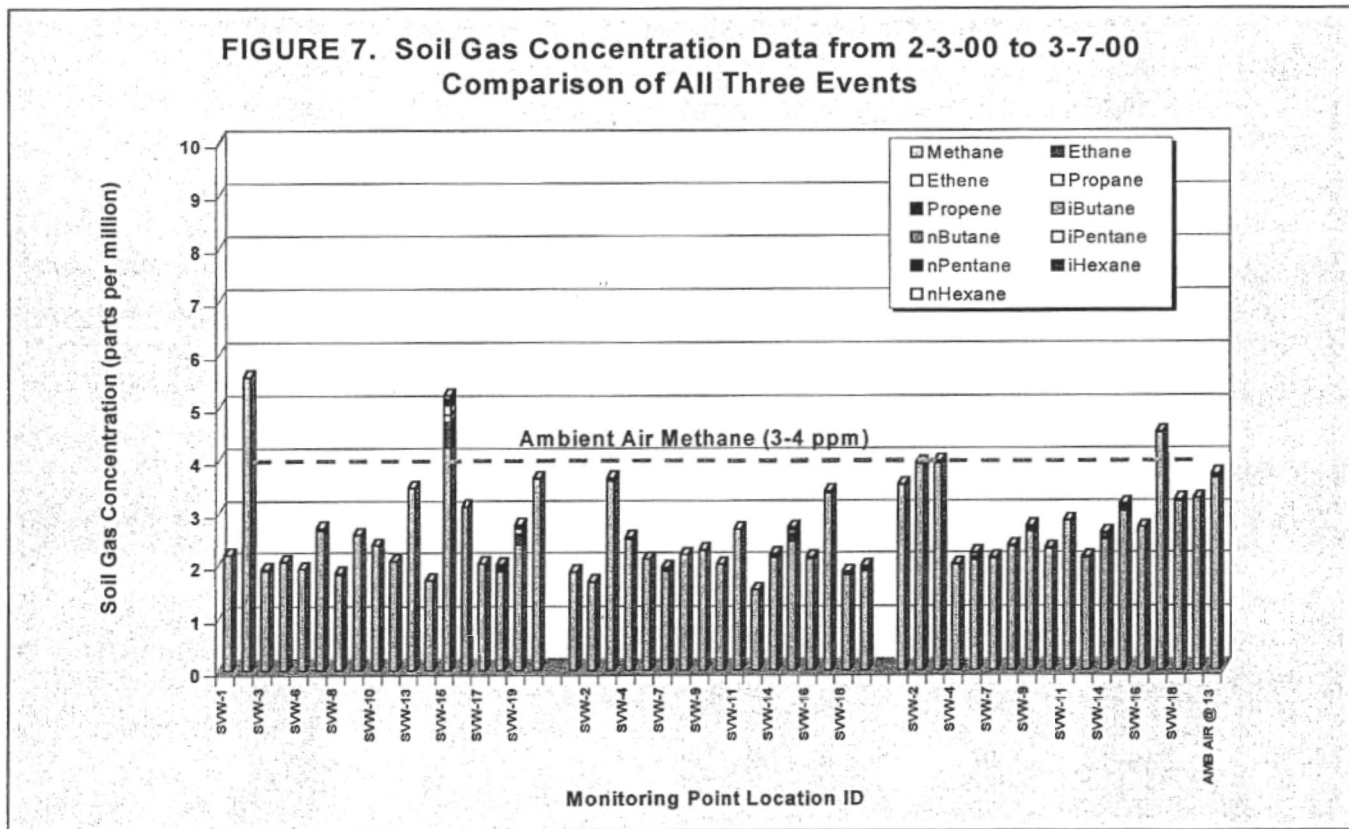


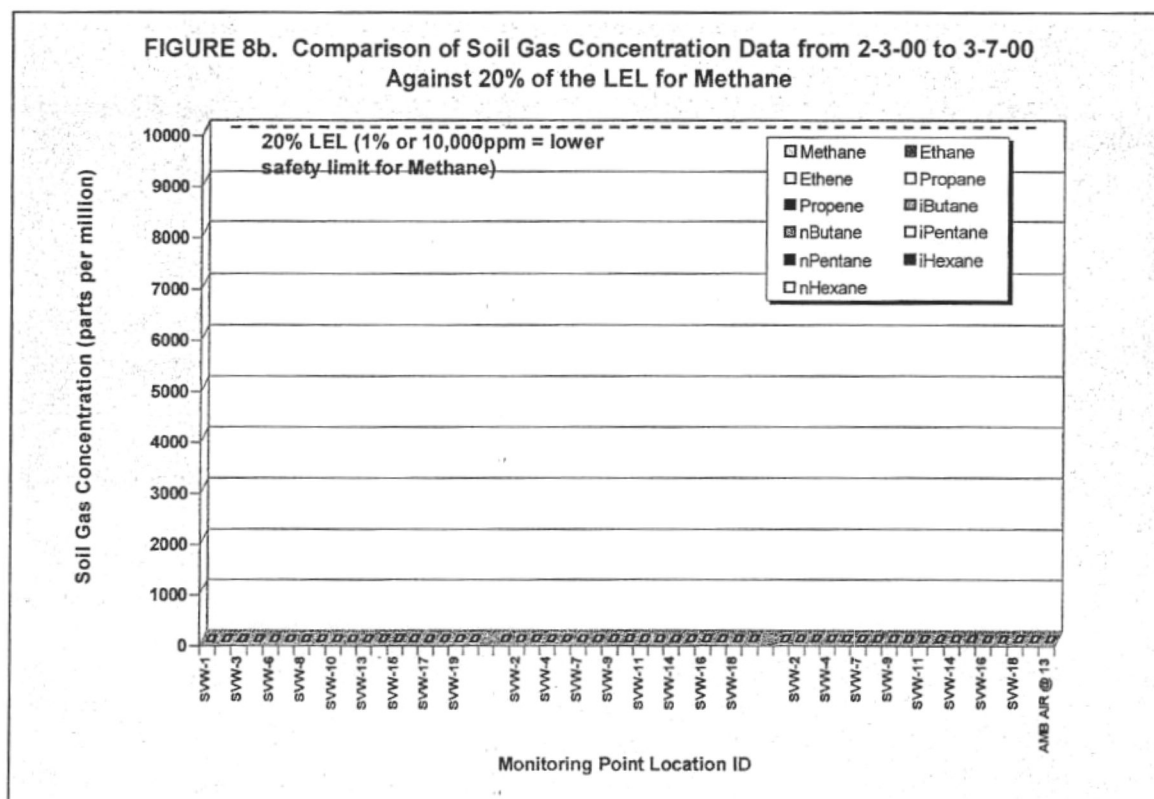
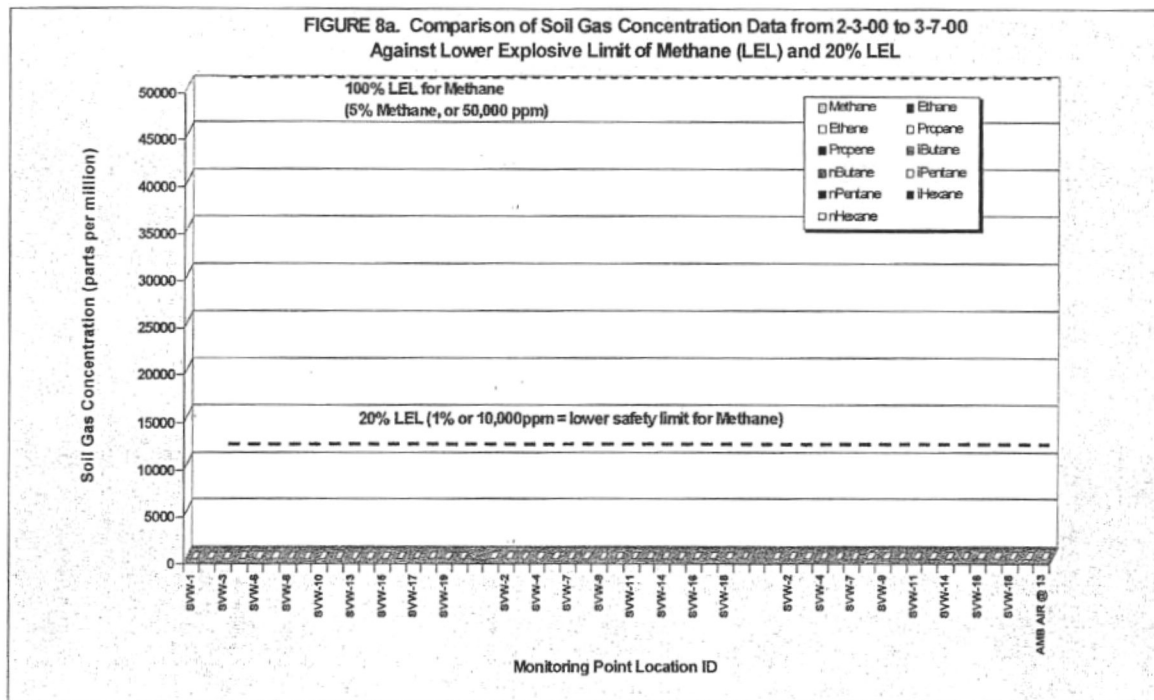
Figure 7 shows all three sampling events on one chart for comparison. This chart shows that all of the measurements are at the level of ambient air methane with no significant increases over that level.



The USEPA (US Environmental Protection Agency) or OSHA (Occupational Safety and Health Administration) only regulates methane as a simple asphyxiant (dilution of oxygen in air) and a flammable gas. Methane and the other light hydrocarbons are not known to be toxic.

To put the above reported values from all three sampling events in perspective, two other charts (Figures 8a and 8b) were created to compare the values to what OSHA and the EPA considers hazardous levels of methane. The first graph compares the values to the Lower Explosive Limit¹ (LEL) of methane, which is 5% methane in air. The second chart compares the values to 20% of the LEL (1% methane), which is the margin of safety applied by OSHA for health and safety. On both charts, none of the values even show up as measurable. This is due to the fact that the highest value measured in this study was 2,000 times lower than the 20% LEL limit.

¹ The lowest concentration in air that could cause an explosion



Statistics and Frequency Distribution Analysis

Frequency Distribution Analysis are statistical methods used to see if data falls in a normal range of variation or not. It is frequently used in resource exploration to identify anomalous data sets. That is, it can help distinguish data that does not follow a Normal Frequency Distribution². If the data set has values that are not part of that distribution, they will show up on a histogram as outliers. It is easier to see this feature with larger data sets, but it has been used with this data to show that the total gas values can be characterized. On a histogram, outlier data would appear as a separate group at the far right of the graph compared to the rest of the background data which would appear in general as a bell shaped curve. With small data sets it is a little difficult to see the "bell shaped curve", however, the data still clusters in a group and outliers can be identified.

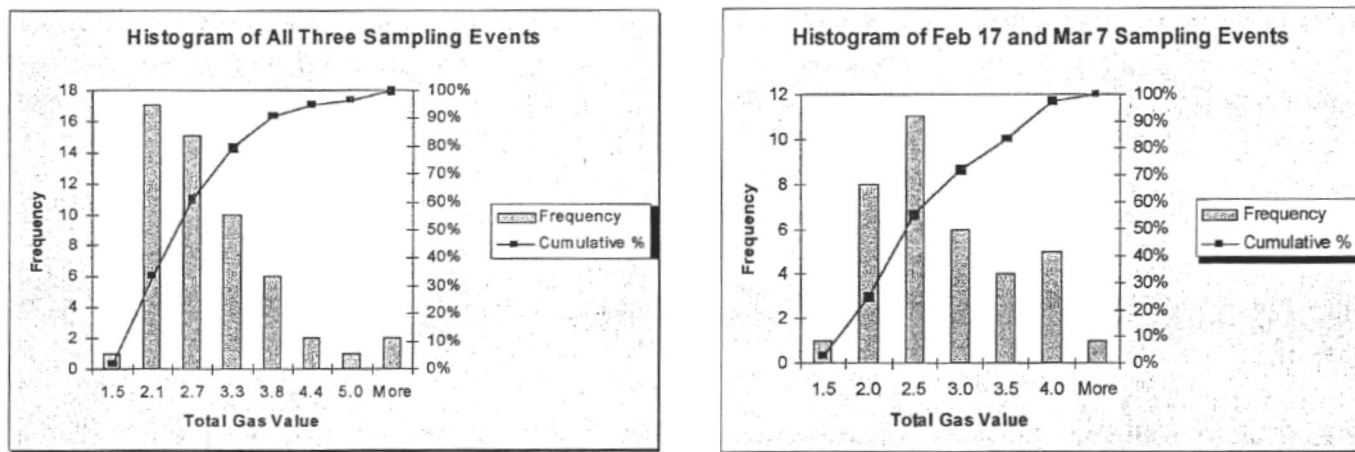


Figure 9. Histograms of the Total Gas from (a) all three sampling events and (b) the last two sampling events.

Figure 9 shows two histograms that were created from the total gas data. The first graph shows all of the data from the three sampling events. It is easy to see that the data is clustered mostly around ambient levels of methane, but a few samples are trying to form outliers at the upper end, but not significantly parted from the rest of the data, as an outlier would be. These points at the upper end are the few highest values in the first sampling event, which was done shortly after the monitoring point installation.

The second histogram includes the data from the two later sampling events, eliminating the February 3rd data. It forms a roughly bell shape cluster of data, around the ambient air methane values. There are no outliers apparent at all. This indicates that the only source of gas in the soil is that occurring naturally in the soil. There are no other sources present such as biogenic methane or leaks from either the facility, or other natural sources.

Other descriptive statistics were generated in Table 1 for all of the samples and the components measured. This information can be used simply to view the amount of variability in a data set and some general characteristics of that data.

² A Normal Frequency Distribution is one that fits the standard bell shaped curve on a frequency distribution histogram.

Table 1. Descriptive Statistics on all three sampling events.

Descriptive Statistics	methane	ethane	ethene	propane	propene	ibutane	nbutane	ipentane	npentane	ihexane	nhexane	total
Mean	2.59	0.03	0.01	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.00	2.65
Median	2.31	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.34
Mode	1.87	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.71
Standard Deviation	0.84	0.07	0.02	0.03	0.01	0.01	0.01	0.00	0.00	0.01	0.00	0.88
Sample Variance	0.70	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.77
Range	4.05	0.49	0.13	0.19	0.09	0.04	0.07	0.01	0.02	0.04	0.01	4.05
Minimum	1.53	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.53
Maximum	5.58	0.49	0.13	0.19	0.09	0.04	0.07	0.01	0.02	0.04	0.01	5.58

Conclusions

Methane is found everywhere in the atmosphere and in soils typically between at 1 to 4 ppm. It can also be found at much higher concentrations (percent levels) where degradation of organic material is present, such as buried plant material, a natural swamp, wetland or estuary, or in a landfill. Ethane and the heavier alkanes (ethane, propane, butane, etc.) are also found in soils at low levels (also variable, but more typically less than 1 ppm), especially in petroleum producing basins.

The analytical procedures used in this study were designed to measure trace amounts of naturally occurring petroleum hydrocarbons in soil gases. These low measurements are routinely done to measure "micro-seepage" over oil and gas prospects in petroleum producing basins. Typically, over such prospective areas, background levels of hydrocarbons are detected and measured, and attempts are made to distinguish these background levels from anomalous levels associated with natural oil and gas accumulations. These background levels are commonly measured in petroleum producing basins, such as the Denver-Julesburg Basin. It should be noted that using this low of a detection limit, it is easy to see background levels of the naturally occurring hydrocarbons, and that these typical background levels do not represent any concern to health and safety.

Ethylene (or ethene) and propylene (or propene), which are light hydrocarbons typically found in soils, are also measured and reported. These two compounds are typically from biodegradation of man-made or naturally occurring hydrocarbons. Ethylene gas is found in other natural biologic processes. These compounds were found at expected low levels in the soil.

The analytical method used detects hydrocarbon gases at 10 parts per billion (0.01 parts per million or 0.00000001%) or more in air. The accepted (USEPA and OSHA) safety limit for methane exposure is the 20 percent of the Lower Explosive Limit (20% LEL) of methane. The LEL for methane is 5% in air, so 20% LEL is 1% methane. The highest value of total gas detected was 5.6 ppm, or 1,785 time less than the LEL.

Using the Frequency Distribution Analysis techniques, it would be possible to also see as outliers from either biologic sources of methane in the soil, seeps from natural reservoirs of oil and/or gas, or leakage from the gas storage reservoir facility. These would show as "outliers" to normal background. If we were to identify these outliers, we would then need to distinguish the sources by looking at the composition of the gases. Biogenic sources are easy to distinguish because they generate mostly methane and carbon dioxide. Distinguishing other types of natural gas sources is more difficult because similar compounds identical to those in the storage reservoir are constantly being emitted from natural petroleum sources in the Denver Basin.

There are more sophisticated statistical tools that can be used to fingerprint the gas composition and determine if it is related to Storage Gas or to naturally occurring gases in the soil. Very few of the samples obtained in the study exhibited hydrocarbons heavier than methane (ethane, propane, or butane). Most samples did so at such low concentrations to render compositional fingerprinting unusable. The highest concentrations of ethane and heavier hydrocarbons occurred during the first round of sampling. After that, detection of ethane and heavier compounds was rare. The levels of hydrocarbons were no different than those found in background survey locations during this study and in previous studies using the same methods.

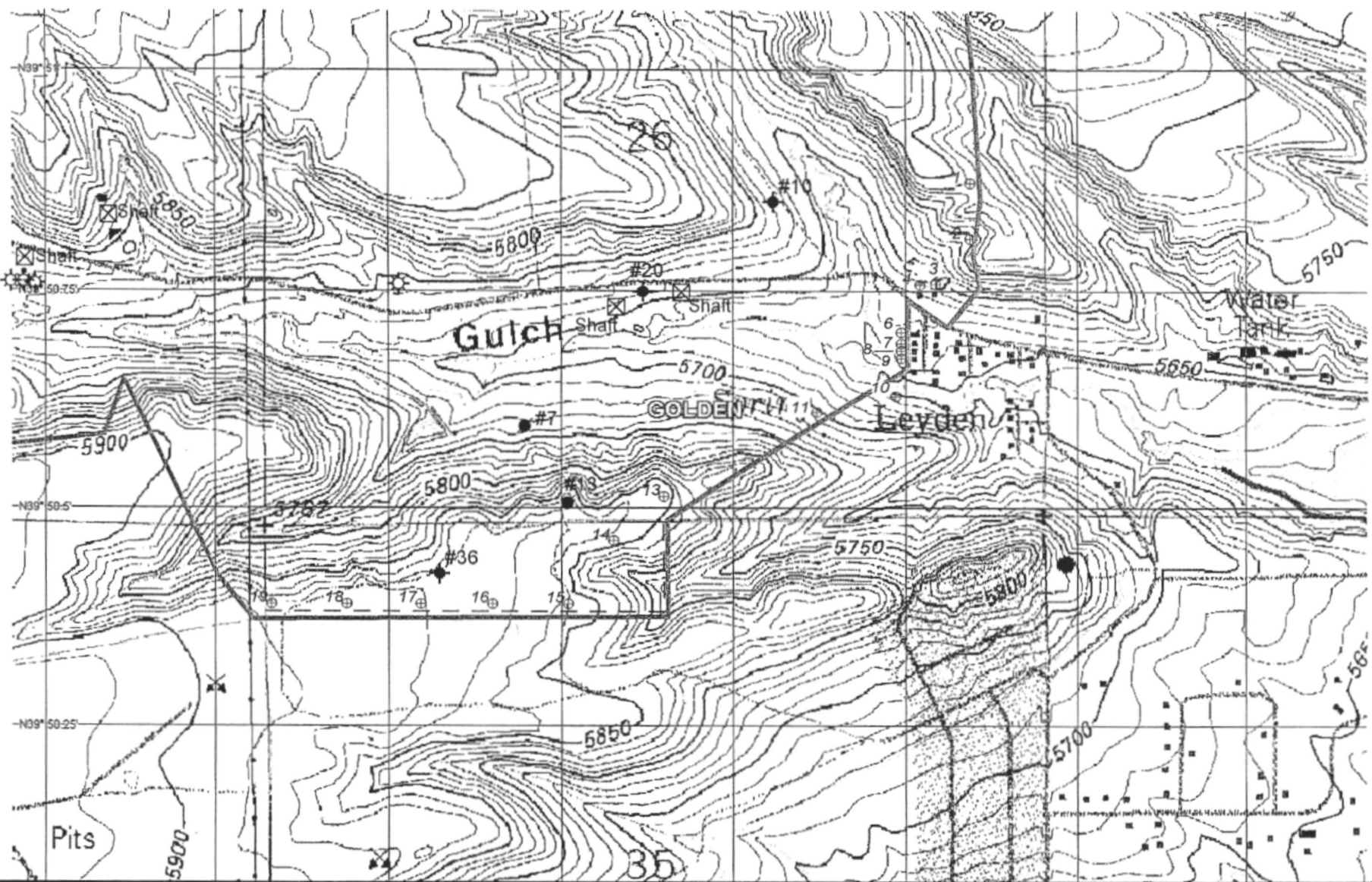
As a result, it is clear that the gases detected in the soil in this investigation cannot be demonstrated to be arising from the Leyden Gas Storage and are indistinguishable from naturally occurring sources. At no time was any gas detected at a concentration that could be considered a risk to public health or safety.

References

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- Whiticar, M.J., 1990, Natural Gas and Atmospheric Methane, *in* J. Organic Geochemistry, V16, No. 1-3, p531. (info on artificial gases)

Appendix A

Monitoring Point Location Map



ESN
ROCKY MOUNTAIN

The Environmental
Services Network

400 Corporate Circle, Suite R
Golden, Colorado 80401
Phone: 303.278-1911
FAX: 303.278.0104
E-Mail: Info@ESN-RM.com

Soil Gas Monitoring Point Locations (Installed 1/28/99)

ESN PROJECT NO.: 0126
CLIENT: Public Service Company of Colorado
PROJECT NAME: Leyden Soil Gas Monitoring
LOCATION: Sec 26 & 35, T2S-R70W, Jefferson County, CO
DRAFTED BY: JVF, 3/1/99

- ⊕ Soil Gas Monitoring Point
- Leyden Gas Storage Buffer Zone Boundary



BASE MAP: USGS 7.5' Quad,
DATUM: WGS84

Scale in Feet



PSC 055914

Appendix B

Soil Gas Data

CLIENT: PUBLIC SERVICE COMPANY OF CO CLIENT PROJECT NO.: Leyden Gas Storage Facility ESN PROJECT NO.: 0126 - Leyden Gas Storage Facility 1st Sampling Event						ESN ROCKY MOUNTAIN Soil Gas Analysis - C1-C6 Hydrocarbons										ESN ROCKY MOUNTAIN C1-C4 Hydrocarbon Composition									
Lab Job#	Field ID	Screened Interval	Bottom Hole (ft)	Run Date	Collection Date	Soil Gas Concentrations (Parts per Million, volume/volume)										Hydrocarbon Composition									
						Methane	Ethane	Ethene	Propane	Propene	iButane	nButane	iPentane	nPentane	iHexane	nHexane	Total	%Methane	%Ethane	%Ethene	%Propane	%Propene	%iButane	%nButane	
	1st Sampling Event																								
0126.01	SVW-1	11-13'	15.0	2/3/00	2/3/00	2.18	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	2.18	100.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
0126.01	SVW-2	12.5-14.5'	15.0	2/3/00	2/3/00	5.58	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	5.58	100.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
0126.01	SVW-3	11.5-13.5'	14.0	2/3/00	2/3/00	1.88	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.02	<0.01	<0.01	1.90	99.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
0126.01	SVW-4	13.5-15.5'	15.5	2/3/00	2/3/00	2.05	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	2.05	100.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
0126.01	SVW-6	10-12'	20.0	2/4/00	2/3/00	1.92	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	1.92	100.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
0126.01	SVW-7	10-12'	12.5	2/4/00	2/3/00	2.65	0.02	<0.01	0.02	0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	2.71	97.93%	0.74%	0.00%	0.89%	0.44%	0.00%	0.00%	0.00%
0126.01	SVW-8	6-8'	8.5	2/4/00	2/3/00	1.81	<0.01	0.01	<0.01	0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	1.83	98.69%	0.00%	0.60%	0.00%	0.71%	0.00%	0.00%	0.00%
0126.01	SVW-9	6-8'	8.5	2/4/00	2/3/00	3.05	<0.01	<0.01	0.02	<0.01	0.02	0.03	<0.01	<0.01	0.01	0.02	3.15	96.95%	0.00%	0.00%	0.64%	0.00%	0.67%	0.92%	0.00%
0126.01	SVW-9 (LD)	6-8'	8.5	2/4/00	2/3/00	3.30	<0.01	<0.01	0.02	<0.01	<0.01	0.03	<0.01	<0.01	<0.01	0.01	3.36	98.33%	0.00%	0.00%	0.54%	0.00%	0.00%	0.80%	0.00%
0126.01	SVW-9 RETAKE	6-8'	8.5	2/4/00	2/4/00	2.57	<0.01	0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	2.58	99.57%	0.00%	0.43%	0.00%	0.00%	0.00%	0.00%	0.00%
0126.01	SVW-10	6-8'	8.5	2/3/00	2/3/00	2.37	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	2.37	100.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
0126.01	SVW-11	8.5-10.5'	11.0	2/3/00	2/3/00	2.06	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	2.06	100.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
0126.01	SVW-13A	13-15'	15.5	2/4/00	2/3/00	3.48	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	3.48	100.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
0126.01	SVW-13B (FD)	13-15'	15.5	2/4/00	2/3/00	2.10	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	2.16	100.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
0126.01	SVW-14	13-15'	15.5	2/4/00	2/3/00	1.71	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	1.71	100.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
0126.01	SVW-15	13-15'	15.5	2/4/00	2/3/00	4.23	0.49	0.13	0.19	0.09	0.03	0.07	<0.01	<0.01	<0.01	<0.01	5.23	80.94%	9.38%	2.49%	3.64%	1.63%	0.61%	1.32%	0.00%
0126.01	SVW-16	2-4'	8.0	2/4/00	2/3/00	3.12	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	3.12	100.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
0126.01	SVW-17	4-6'	8.0	2/4/00	2/3/00	2.02	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	2.02	100.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
0126.01	SVW-18	9.5-11.5'	12.0	2/4/00	2/3/00	1.87	0.05	0.02	0.04	0.02	<0.01	0.01	<0.01	<0.01	<0.01	<0.01	2.00	93.31%	2.50%	1.10%	1.65%	0.75%	0.00%	0.50%	0.00%
0126.01	SVW-19	9.5-11.5'	12.0	2/4/00	2/3/00	2.37	0.19	0.03	0.10	0.03	0.02	0.03	<0.01	<0.01	<0.01	<0.01	2.77	85.65%	6.72%	1.19%	3.43%	1.19%	0.76%	1.05%	0.00%
0126.01	SVW-19 (LD)	9.5-11.5'	12.0	2/4/00	2/3/00	2.09	0.28	<0.01	0.09	0.04	0.02	0.03	<0.01	<0.01	<0.01	<0.01	2.55	82.09%	10.92%	0.00%	3.38%	1.45%	0.86%	1.30%	0.00%
0126.01	TRIP BLANK			2/4/00	2/3/00	0.02	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.02	100.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
0126.01	TEG-SV-TEST-1			2/4/00	2/4/00	1.84	<0.01	0.01	<0.01	<0.01	0.02	<0.01	<0.01	<0.01	<0.01	<0.01	1.87	98.28%	0.00%	0.59%	0.00%	0.00%	1.12%	0.00%	0.00%
0126.01	AMB AIR @ 15'			2/4/00	2/4/00	3.64	<0.01	0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	3.65	99.70%	0.00%	0.30%	0.00%	0.00%	0.00%	0.00%	0.00%
ABBREVIATIONS						TB = Trip Blank MB = Method Blank FB = Field Blank										FD = Field Duplicate LD = Laboratory Duplicate LS = Laboratory Spike									

PSC 055916

CLIENT: PUBLIC SERVICE COMPANY OF CO CLIENT PROJECT NO.: Leyden Gas Storage Facility TEG PROJECT NO.: 0126 - Leyden Gas Storage Facility 2nd Sampling Event						ESN ROCKY MOUNTAIN Soil Gas Analysis - C1-C6 Hydrocarbons											ESN ROCKY MOUNTAIN C1-C4 Hydrocarbon Composition								
Lab Job#	Field ID	Screened Interval	Bottom Hole (ft)	Run Date	Collection Date	Soil Gas Concentrations (Parts per Million, volume/volume)											Hydrocarbon Composition								
						Methano	Ethane	Ethene	Propane	Propene	iButane	nButane	iPentane	nPentane	iHexane	nHexane	Total	%Methane	%Ethane	%Ethene	%Propane	%Propene	%iButane	%nButane	
	2nd Sampling Event																								
0126.02	SVW-1	11-13'	15.0	2/17/00	2/17/00	1.88	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	1.86	100.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
0126.02	SVW-2	12.5-14.5'	15.0	2/17/00	2/17/00	1.68	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	1.68	100.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
0126.02	SVW-3	11.5-13.5'	14.0	2/18/00	2/17/00	3.61	0.02	0.02	<0.01	<0.01	<0.01	0.01	<0.01	<0.01	<0.01	<0.01	3.66	98.63%	0.55%	0.55%	0.00%	0.00%	0.00%	0.00%	0.27%
0126.02	SVW-4	13.5-15.5'	15.5	2/18/00	2/17/00	2.48	<0.01	0.02	<0.01	<0.01	0.01	0.01	<0.01	<0.01	<0.01	<0.01	2.52	98.41%	0.00%	0.79%	0.00%	0.00%	0.40%	0.40%	
0126.02	SVW-6	10-12'	20.0	2/18/00	2/17/00	2.10	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	2.10	100.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	
0126.02	SVW-7	10-12'	12.5	2/18/00	2/17/00	1.87	0.02	0.01	0.01	0.02	0.01	<0.01	<0.01	<0.01	<0.01	<0.01	1.84	96.39%	1.03%	0.52%	0.52%	1.03%	0.52%	0.00%	
0126.02	SVW-8	6-8'	8.5	2/18/00	2/17/00	2.19	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	2.19	100.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	
0126.02	SVW-9	6-8'	8.5	2/18/00	2/17/00	2.28	0.02	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	2.28	99.12%	0.88%	0.00%	0.00%	0.00%	0.00%	0.00%	
0126.02	SVW-10	6-8'	8.5	2/18/00	2/17/00	2.00	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	2.00	100.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	
0126.02	SVW-11	8.5-10.5'	11.0	2/18/00	2/17/00	2.68	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	2.68	100.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	
0126.02	SVW-13	13-15'	15.5	2/18/00	2/17/00	1.53	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	1.53	100.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	
0126.02	SVW-14	13-15'	15.5	02/24/00	02/24/00	2.13	0.03	<0.01	0.02	<0.01	<0.01	0.01	<0.01	<0.01	<0.01	<0.01	2.20	96.81%	1.50%	0.00%	1.09%	0.00%	0.00%	0.59%	
0126.02	SVW-15.1	13-15'	15.5	2/18/00	2/17/00	2.44	0.02	0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	2.47	98.79%	0.81%	0.40%	0.00%	0.00%	0.00%	0.00%	
0126.02	SVW-15.2 (FD)	13-15'	15.5	2/18/00	2/17/00	1.83	0.11	0.03	0.06	0.01	0.02	0.02	<0.01	<0.01	<0.01	<0.01	2.08	87.98%	5.29%	1.44%	2.88%	0.48%	0.96%	0.96%	
0126.02	SVW-15.2 (LD)	13-15'	15.5	2/18/00	2/17/00	2.44	0.12	0.03	0.05	0.02	0.02	0.02	<0.01	<0.01	<0.01	<0.01	2.71	90.04%	4.43%	1.11%	2.21%	0.74%	0.74%	0.74%	
0126.02	SVW-16	2-4'	8.0	2/18/00	2/17/00	2.10	0.02	<0.01	<0.01	<0.01	0.02	<0.01	<0.01	<0.01	<0.01	<0.01	2.14	98.13%	0.93%	0.00%	0.00%	0.00%	0.93%	0.00%	
0126.02	SVW-17	4-6'	8.0	2/18/00	2/17/00	3.37	<0.01	<0.01	<0.01	<0.01	<0.01	0.04	<0.01	<0.01	<0.01	<0.01	3.41	98.83%	0.00%	0.00%	0.00%	0.00%	0.00%	1.17%	
0126.02	SVW-18	9.5-11.5'	12.0	02/24/00	02/24/00	1.80	0.04	<0.01	0.02	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	1.85	97.09%	2.00%	0.00%	0.92%	0.00%	0.00%	0.00%	
0126.02	SVW-18 (LD)	9.5-11.5'	12.0	02/24/00	02/24/00	1.61	0.03	0.02	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	1.66	97.16%	1.93%	0.91%	0.00%	0.00%	0.00%	0.00%	
0126.02	SVW-19	9.5-11.5'	12.0	02/24/00	02/24/00	1.87	0.04	0.01	0.03	0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	1.97	95.07%	1.98%	0.71%	1.68%	0.56%	0.00%	0.00%	
0126.02	MB			02/24/00	02/24/00	0.30	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.30	100.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	
ABBREVIATIONS																									
TB = Trip Blank						FD = Field Duplicate																			
MB = Method Blank						LD = Laboratory Duplicate																			
FB = Field Blank						LS = Laboratory Spike																			

PSC 055917

CLIENT: PUBLIC SERVICE COMPANY OF CO						ESN ROCKY MOUNTAIN										ESN ROCKY MOUNTAIN									
CLIENT PROJECT NO.: Leyden Gas Storage Facility						Soil Gas Analysis - C1-C6 Hydrocarbons										Soil Gas Composition - C1-C6 Hydrocarbons									
TEG PROJECT NO.: 0126 - Leyden Gas Storage Facility																									
3rd Sampling Event																									
Lab Job#	Field ID	Screened Interval	Bottom Hole (ft)	Run Date	Collection Date	Soil Gas Concentrations (Parts per Million, volume/volume)										Hydrocarbon Composition									
						Methane	Ethane	Ethene	Propane	Propene	iButane	nButane	iPentane	nPentane	Hexene	nHexane	Total	%Methane	%Ethane	%Ethene	%Propane	%Propene	%iButane	%nButane	
	Sampling Event																								
0126.03	SVW-1	11-13'	15.0	3/15/2000	3/7/2000	3.52	0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	3.53	99.63%	0.37%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
0126.03	SVW-2	12.5-14.5'	15.0	3/15/2000	3/7/2000	3.91	0.02	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	3.93	99.57%	0.43%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
0126.03	SVW-3	11.5-13.5'	14.0	3/15/2000	3/7/2000	3.92	0.04	<0.01	<0.01	<0.01	0.02	<0.01	<0.01	<0.01	<0.01	3.97	98.57%	1.01%	0.00%	0.00%	0.00%	0.00%	0.43%	0.00%	0.00%
0126.03	SVW-4	13.5-15.5'	15.5	3/15/2000	3/7/2000	1.99	<0.01	<0.01	<0.01	<0.01	0.02	<0.01	<0.01	<0.01	<0.01	2.01	99.20%	0.00%	0.00%	0.00%	0.00%	0.00%	0.60%	0.00%	0.00%
0126.03	SVW-6	10-12'	20.0	3/15/2000	3/7/2000	2.08	0.05	0.01	0.06	<0.01	<0.01	<0.01	0.01	<0.01	0.01	2.23	93.34%	2.21%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
0126.03	SVW-7	10-12'	12.5	3/15/2000	3/7/2000	2.10	0.03	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	2.12	98.82%	1.18%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
0126.03	SVW-8	6-8'	8.5	3/15/2000	3/7/2000	2.33	<0.01	<0.01	<0.01	<0.01	0.03	<0.01	<0.01	<0.01	<0.01	2.36	98.77%	0.00%	0.00%	0.00%	0.00%	0.00%	1.23%	0.00%	0.00%
0126.03	SVW-9	6-8'	8.5	3/15/2000	3/7/2000	2.63	0.07	<0.01	<0.01	<0.01	0.04	<0.01	<0.01	<0.01	<0.01	2.74	95.93%	2.61%	0.00%	0.00%	0.00%	0.00%	1.46%	0.00%	0.00%
0126.03	SVW-10	6-8'	8.5	3/15/2000	3/7/2000	2.29	<0.01	0.01	<0.01	0.01	<0.01	<0.01	<0.01	<0.01	<0.01	2.31	98.96%	0.00%	0.56%	0.48%	0.00%	0.00%	0.00%	0.00%	0.00%
0126.03	SVW-11	8.5-10.5'	11.0	3/15/2000	3/7/2000	2.83	<0.01	0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	2.85	99.51%	0.00%	0.49%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
0126.03	SVW-13	13-15'	15.5	3/15/2000	3/7/2000	2.12	0.02	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	2.14	98.97%	1.03%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
0126.03	SVW-14	13-15'	15.5	3/15/2000	3/7/2000	2.47	0.05	0.05	<0.01	<0.01	0.01	<0.01	<0.01	0.02	<0.01	2.61	94.74%	1.84%	1.76%	0.00%	0.00%	0.00%	0.54%	0.00%	0.00%
0126.03	SVW-14 DUP	13-15'	15.5	3/15/2000	3/7/2000	2.08	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.01	<0.01	0.38	2.47	84.14%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
0126.03	SVW-15	13-15'	15.5	3/15/2000	3/7/2000	3.02	0.06	<0.01	0.02	<0.01	0.02	0.03	<0.01	<0.01	<0.01	3.16	95.58%	1.90%	0.00%	0.76%	0.00%	0.00%	0.69%	1.07%	0.00%
0126.03	SVW-16	2-4'	8.0	3/15/2000	3/7/2000	2.71	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	2.71	100.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
0126.03	SVW-17	4-6'	8.0	3/15/2000	3/7/2000	4.51	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.01	<0.01	<0.01	4.52	99.76%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
0126.03	SVW-18	9.5-11.5'	12.0	3/15/2000	3/7/2000	3.20	0.02	<0.01	<0.01	<0.01	0.03	<0.01	<0.01	<0.01	<0.01	3.24	98.67%	0.56%	0.00%	0.00%	0.00%	0.00%	0.77%	0.00%	0.00%
0126.03	SVW-19	9.5-11.5'	12.0	3/15/2000	3/7/2000	3.26	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	3.26	100.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
0126.03	AMB AIR @ #13					3.65	0.03	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.04	3.72	98.17%	0.70%							
ABBREVIATIONS																									
TB = Trip Blank						FD = Field Duplicate																			
MB = Method Blank						LD = Laboratory Duplicate																			
FB = Field Blank						LS = Laboratory Spike																			

PSC 055918

Appendix C - Soil Gas Data from Previous Studies

Table 2. Comparison of soil gas compositions from analysis from Isotech Study at the NWIS-II property, Rocky Mountain Consultants/Direct Geochemical 1996 study at Conda property, and the 1998 TEG Golden Area Background Soil Gas Study.

	Methane	Ethane	Propane	Butanes	Total	Units
Leyden Storage Gas Composition						
Inlet Plant Sample	82.76 91.2%	6.97 7.7%	0.86 1.0%	0.14 0.1%	90.73 100%	% of Gas Norm. HC %
DGI/TEG Conda-96 Data (highest values)						
SG-1A	140 99.9%	0.08 0.1%	0.04 0.0%	0 0.0%	140.12 100%	PPM Norm. HC %
SG-2	3.7 89.2%	0.31 7.5%	0.11 2.7%	0.03 0.7%	4.15 100%	PPM Norm. HC %
SG-5A	3.1 84.5%	0.41 11.2%	0.12 3.3%	0.04 1.1%	3.67 100%	PPM Norm. HC %
Golden Area Background - Active Sampling, May 22-26 (highest values)						
VS-001	11 78.2%	2.17 15.4%	0.68 4.8%	0.21 1.5%	14.06 100%	PPM Norm. HC %
VS-002	4.5 82.7%	0.62 11.4%	0.22 4.0%	0.1 1.8%	5.44 100%	PPM Norm. HC %
VS-003	2.94 81.7%	0.33 9.2%	0.15 4.2%	0.18 5.0%	3.6 100%	PPM Norm. HC %
Golden Area Background - Soil Gas Implant Sampling, June 5-6						
VS-001	0.32	0.02	0.02	ND	ND	PPM
VS-002	0.05	ND	0.02	0.03	ND	PPM
VS-003	0.05	ND	0.08	0.08	0.11	PPM

Norm. HC % - Normalized to Percent of Total (Alkane) Hydrocarbons

PPM - Parts per Million

ND = non-detect

Total Hydrocarbons include the sum of the C₁-C₄ alkanes only. The Normalized Percent of Hydrocarbons is based on the alkanes only. There were not enough detected components to calculate percent composition in the Golden Area Background data.

Appendix D

Field Soil Core Lithology Logs

teg Rocky Mountain

GEOLOGIC BORING LOG

Sheet 1 of 1

BORING NO. * 2
 CLIENT PSSC
 JOB NO. 0126
 LOCATION LETEN
 GEOLOGIST _____
 COMMENTS _____

RIG TYPE SP
 DRLG. METHOD MC
 BORING DIA. 2"
 TOT. DEPTH 15'
 OPERATOR S.L

DATE SPUD 1/28/00
 DATE COMPL _____
 ELEVATION _____
 TEMP _____
 WEATHER _____
 WATER DEPTH _____

Depth (Feet)	Profile	USCS	Geologic Description	Sample		Chemical Analysis		
				No.	Depth	PID		
1			TOP SOIL					
	0.0		DARK BR. CLAY w/ RED STEAKS					
	0.1		GRAVELS PRESENT THROUGHOUT					
	0.2		LAYER					
5	0.3							
	0.4							
	0.5							
	0.6							
	0.7							
10	0.8		RED/ORANGE FETTERIC					
	0.9		CLAYSTONE, SOFT					
	1.0							
	1.1		REDISH STEAKS					
	1.2							
15	1.3		FETTERIC, HARD/DENSE					
	1.4		2 REFUSAL					
	1.5							
	1.6							
20	1.7							
	1.8							
	1.9							
25	2.0							
	2.1							
	2.2							
30	2.3							
	2.4							
	2.5							
35	2.6							
	2.7							
	2.8							
40	2.9							

NOTES:

GEOLOGIC BORING LOG

Sheet 1 of 1

BORING NO. *6
 CLIENT PSSC
 JOB NO. 0126
 LOCATION LYDEN
 GEOLOGIST _____
 COMMENTS _____

RIG TYPE SP
 DRLG. METHOD MC
 BORING DIA. 2"
 TOT. DEPTH 20'
 OPERATOR J.L.

DATE SPUD 1/28/00
 DATE COMPL _____
 ELEVATION _____
 TEMP _____
 WEATHER _____
 WATER DEPTH _____

Depth (Feet)	Profile	USCS	Geologic Description	Sample		Chemical Analysis		
				No.	Depth	PID		
1			TOPSOIL - DARK BR. CLAY P.C. 11					
			LT. BR. CLAY 10% SAND					
			GRAVEL					
5			BR. CLAY					
			U/10% SAND					
			60% FINE SAND					
10			BR. CLAY					
			10% SAND					
15								
			GRAVEL, F+ STAINED					
20			H ₂ O SATURATED WEATHERED BED ROCK					
			2 - REFUSAL					
25								
30								
35								
40								

NOTES:

GEOLOGIC BORING LOG

Sheet 1 of 1

BORING NO. * 16
 CLIENT PSSC
 JOB NO. 0126
 LOCATION LEIDEN
 GEOLOGIST _____
 COMMENTS _____

RIG TYPE SP
 DRLG. METHOD MC
 BORING DIA. 2"
 TOT. DEPTH 8'
 OPERATOR J.L.

DATE SPUD 1/20/00
 DATE COMPL. _____
 ELEVATION _____
 TEMP _____
 WEATHER CLOUD
 WATER DEPTH _____

Depth (Feet)	Profile	USCS	Geologic Description	Sample		Chemical Analysis		
				No.	Depth	PID		
1			50% CLAY / SAND FINE GRAINED, GRAVEL BEDS 1"-4" PRESENT WITH DISPERSED GRAVEL PRESENT THROUGHOUT.					
2								
3								
4								
5								
6								
7								
8								
10								
15								
20								
25								
30								
35								
40								

NOTES:
